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Traceability of high current measurements in short circuit laboratories

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To establish traceability for high current measurements, comparison tests of high current shunts in High Power Laboratories have been carried out with STL reference shunts since 2005. This paper describes the comparison test results of shunts in High Power Laboratory CPRI Bangalore. The test results shown are the shunts tested for the comparison tests performed and most of the differences of the scale factor with power frequency current between the reference shunt and those tested in participating laboratories were less than 0.7 %.

Keywords: *High current shunt, high power laboratories, uncertainty, intercomparision.*

1.0 INTRODUCTION

High current measuring systems used in high power testing have only been investigated to a limited extent, since the current sources required are available only in a few test laboratories. In view of the uncertainties involved in such high current measurement the Short-Circuit Testing Liaison (STL) have investigated whether these systems could be traceable to a measurement standard. The research project of the intercomparision tests of measuring system supported by the E.C (European Commission Project) have been carried out from 1995 to 1997 [1]. In this project, intercomparision tests at 7 European high power laboratories (all except one of which STL member laboratories) were carried out on two transfer measuring systems (shunt, CT and Rogowski coil) including optical data acquisition system to eliminate interference and their own measuring systems were evaluated. The results demonstrated that comparison results at power frequency currents would be necessary.

To establish traceability for high current measurements, STL has carried out comparison tests of high current shunts in high power laboratories since 2005. The concept of the project involves providing STL traceable shunts only and leaving the necessary components to cover a complete reference measuring system to the laboratories themselves. Two STL reference shunts (herein after called reference shunts) were made; one of which is used for Asia and the other for Europe and Africa. In this paper outline of the world wide shunt project, the test results of the comparison test in Asian high power laboratories and technical data of the reference shunt for Asia are described.

2.0 OUTLINE OF THE SHUNT PROJECT

Short –circuit Testing Liaison (STL)

It is a Group of International Certification Bodies concerning the type testing of high voltage electrical power equipment. STLA (called STL) was founded in 1969. STL is a world renowned premier body for harmonized application of IEC recommendations to the type testing of electrical equipment and uniform presentation of the test results. The present STL members are the 09 organisations and they are

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1. ASTA – UK.
2. CESI – Italy.
3. CPRI – India.
4. ESEF – France.
5. KEMA – Netherland.
6. PEHLA – Germany.
7. SATS - Scandinavian Countries.
8. STLNA - North America.
9. JSTC – Japan.

While few other organisations from all over the world have associated with the STL Technical Committee as participants.

2.1 Shunt project [2]-[3]

To establish traceability for high current measurements STL has carried out comparison tests on high current shunts in high power laboratories. The concept of the project involves providing traceable reference shunts only and leaving the necessary remaining components to cover a complete reference measuring systems to the laboratories themselves.

To provide a worldwide service, two reference shunts have been developed, one of which is used for Asia under the responsibility of JSTC (Japan Short-circuit testing committee), CRIEPI as the owner laboratory and the other for Europe and Africa under the responsibility of the European member laboratory (IPH Berlin). The two reference shunts were designed by JSTC and IPH because of avoiding common mistakes for design of the reference shunts. Figure 1 shows reference shunt for Asia; the main technical data for the design of which are shown in Table 1. After calibration, two reference shunts and the EdF (Electricite de France) shunt used in the EC project were compared at the IPH high power laboratory in Germany in May 2005. During the inter-comparison tests the reference shunts were tested to their maximum values.

The participating laboratory will test their current sensors using the reference shunt with their own data transmission, acquisition and recording systems and their own data evaluation software, all of which must be calibrated by the laboratory. Each laboratory also decides which current sensors, shunt, Rogowski coil, current transformer etc. they calibrate and what type of current.

After the comparison test at each laboratory the reference shunt will be sent back to the owner laboratory, which will subsequently measure the resistance value.

After five years the calibration and inter comparison tests will be repeated and the procedure will restart.

2.1.1 Characteristics of the reference shunt

FIG. 1 REFERENCE SHUNT FOR ASIA

TABLE 1

MAIN TECHNICAL DATA OF THE REFERENCE SHUNT FOR DESIGN

Maximum-value of symmetrical current	140 kA, 0.1 s
Maximum peak-value of asymmetrical current	350 kA
Band width	0 – 10 kHz
Time Interval between two tests at full current	1 hour

Figure 1 shows the photograph of reference shunt. Table 1 shows the main technical data of the reference shunt of Asia. The reference shunt is of the coaxial type and was designed by JSTC to withstand huge electromagnetic force due to the high asymmetrical current up to 350 kA peak by JSTC. The resistance of the reference shunt is 51.573 μΩ, which was calibrated with a DC current at the DKD (Deutscher Kalibrierdienst) laboratory and with alternating currents up to 10 kHz by PTB (Physikalisch-Technische Bundesanstalt), in Germany in 2004. The relative AC-DC current difference d_f of the reference shunt is defined as follows:

$$d_f = \frac{U_{af} - U_{ao}}{U_{ao}} \text{ x } 100 \quad ....(1)$$

Where,

d_f = AC-DC current difference,

U_{af} = Output voltage at frequency f

U_{ao} = Output voltage at direct current

Due to inductance the difference becomes larger as the frequency of current becomes high. The measurement results are as shown in Figure 2. The difference is less than 1% at 10 kHz because the thin plate used for the shunt resistor results in reducing the inductance. The frequency characteristics of the reference shunt are excellent and satisfy the requirements of the STL as the reference shunt.

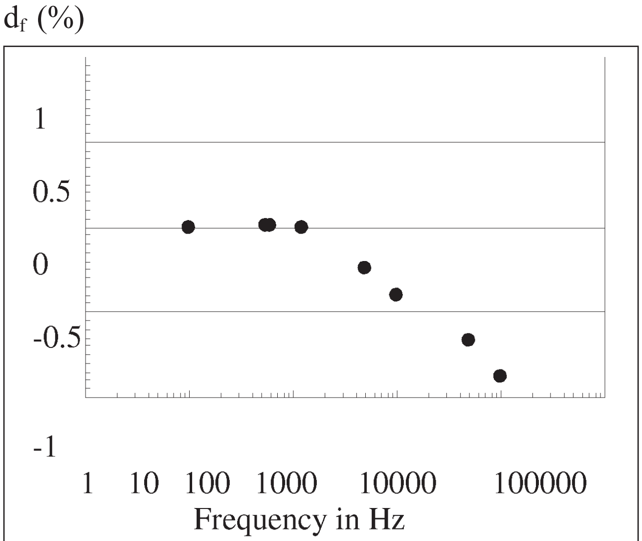

FIG. 2 FREQUENCY CHARACTERISTICS OF REFERENCE SHUNT

TABLE 2

MAIN TECHNICAL DATA OF THE REFERENCE SHUNT FOR ASIA

Type	Coaxial Shunt
Material of Shunt Resistor	Manganin
Maxrms-value of symmetrical current	140 kA, 0.1 s
Max peak-value of asymmetrical current	350 kA
Nominal Resistance	50 uΩ
Band width	0 – 10 kHz
Cooling	Natural
Weight	120 kg

2.1.2 Current withstand tests of the reference shunt

Before starting with the inter-comparison tests of two reference shunts at IPH in Germany, the reference shunt for Asia was tested at CRIEPI, in Japan in February 2003. This applied in particular to its current capability for the power frequency current range upto the maximum rating.

Table 3 shows the test conditions of power frequency tests. The asymmetrical current test was repeated 10 times. The time interval between tests was 30 minutes. During the power frequency tests, the inner surface temperature of the cylindrical shunt resistor made of Manganin was measured using a Cu/Cu-Ni thermocouple 0.32 mm in diameter. Figure 4 shows the temperature measured during the power frequency tests, which were carried out at the outdoor test yard. The temperature was measured since just after the current interruption to just before starting the next test due to the need to protect the measuring instruments from high current interference during current duration. The time between the first and second measurement is longer than 30 minutes, because the test circuit was reinforced to withstand the huge electromagnetic force. The maximum temperature rise of the shunt resistor was about 59 K and the temperature decayed exponentially. At 30 minutes or so after the 10^{th} tests had finished, the temperature of the shunt resistor was about 37 ^{0}C, some 25 ^{0}C higher than the atmospheric temperature [5]. The test results show that the reference shunt can be used at the maximum current rating of 140 kA 0.1 s in asymmetrical power frequency current in intervals of about 30 minutes. No visual damage was recorded during any of the current withstand tests and the test results showed the reference shunt was good enough as a reference.

TABLE 3	
TEST CONDITIONS WITH POWER FREQUENCY CURRENT FOR CURRENT WITHSTAND TESTS	
Frequency	50 Hz
R.m.s value of the asymmetrical current	140 kA
Peak value of the asymmetrical current	350 kA
Duration	0.1 s
Number of tests	10
Time interval between two shots	30 min.

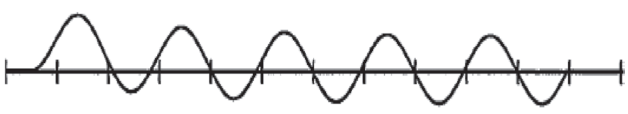

FIG. 3 TYPICAL ASYMMETRICAL POWER FREQUENCY CURRENT

3.0 SUMMARY OF THE INTER-COMPARISON TESTS OF THE REFERENCE SHUNTS

After the initial calibration by the calibration institute, two reference shunts and the CPRI shunt used in the EC project were compared at the high power laboratory of IPH in Germany in May 2005. Table 4 shows the main technical data of the CPRI shunt.

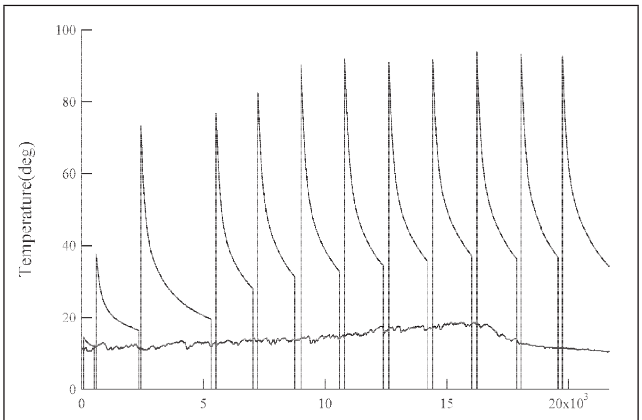

FIG. 4 TEMPERATURE OF THE INNER SURFACE OF THE CYLINDRICAL SHUNT RESISTOR

3.1 Tests with power frequency current

The tests were carried out up to the maximum current values. The tests with power frequency current of 50 Hz were as follows:

(a) Scale factor tests at 10 kA, 0.1 s.

(b) Linearity tests with asymmetrical currents at 20 %, 40 %, 60 %, 80 % and 100 % of the maximum value having a ratio of 2.5 between the peak and r.m.s. values.

(c) Interference tests with an asymmetrical current of 80 % of the maximum value having a ratio of 2.5 between the peak and r.m.s values.

Figure 5 shows the arrangement for the scale factor tests and the linearity tests with power frequency current. All Shunts operated were connected in series. Table 5 shows the test results of the linearity tests. The values of differences were determined to compare with the CPRI shunt and as shown in the figure, were less than 0.5%.

Figure 8 shows the arrangement for the interference tests with the power frequency current. The shunt under test was disconnected and placed open-circuited at a distance of 0.5 min parallel to the conductor in the test circuit and one terminal of the shunt tested was connected to the conductor. The current was measured as an average value by two current carrying shunts. The interference is defined as the ratio between the currents measured in the disconnected shunt relative to the actual current. Table 6 shows the test results, with a very small interference value of 0.071 %.

FIG. 5 150 KA TRANSIENT RESPONSE CT

FIG. 6 140 KA SHUNTS

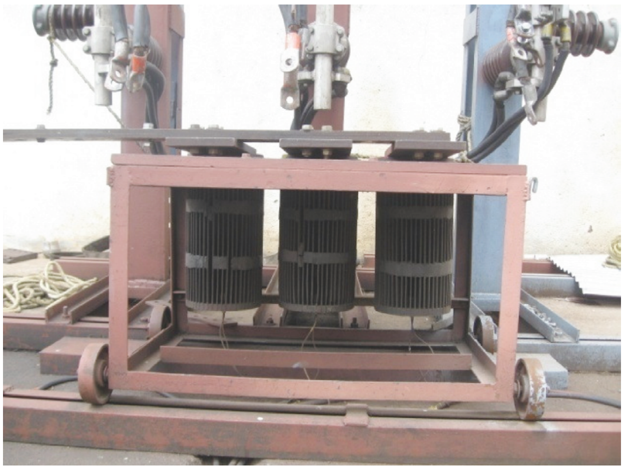

FIG. 7 100 KA SHUNT

3.2 Tests with high frequency current

The interference tests at a high frequency current were carried out under the conditions of a sinus wave current at a frequency of 9 kHz and a maximum peak current of 3 kA. As shown in Table 5 the interference values are 0.07 and 0.15 %.

The test results of the inter-comparison tests shows that two reference shunts made by JSTC and IPH are good enough as references.

4.0 COMPARISON TESTS IN ASIA

After the inter-comparison tests at IHP, in Germany, comparison tests at high power laboratories started in September 2005. From September 2005 to October 2009 High power laboratories in Japan, Korea, China and India completed testing. Most of the laboratories attending the comparison tests were member laboratories of the STL member organization and the organizations participating in the STL Technical Committee meeting. In the paper, the test data of 12 laboratories shown in the Appendix were used for the investigation. Information about the shunts tested at each Laboratory and used in the paper is shown in the Table 6.

4.1 Procedure of the circulation

CPIEPI, the owner laboratory of the reference shunt for Asia, keeps the reference shunt and based on the request by the relevant test laboratory, the reference shunt will be transported. The resistances of the reference shunt is measured before sending to the requested laboratory and also after receiving back by CRIEPI Member laboratory measures the resistance of the reference shunt on its arrival and before sending it back, to check the conditions of the reference shunt the threshold of the difference between the measured and calibrated values by DKD was defined as 0.5 % of the calibrated value.

4.2 Test results

Scale factor tests with power frequency current Figure 5 shows example arrangements of the shunt/CT tested and the reference shunts for the scale factor and linearity tests with power frequency currents. Figure 9, 10, 11 shows the CT and Shunts used in High Power Laboratory, CPRI. Figure 5 shows a typical test circuit and measuring system. The shunt tested and the reference shunt were connected in series in the test circuit, while the outputs of the shunts were measured with 14 bit resolution and the maximum sampling rate of 10 Mega samples/s optical data acquisition system.

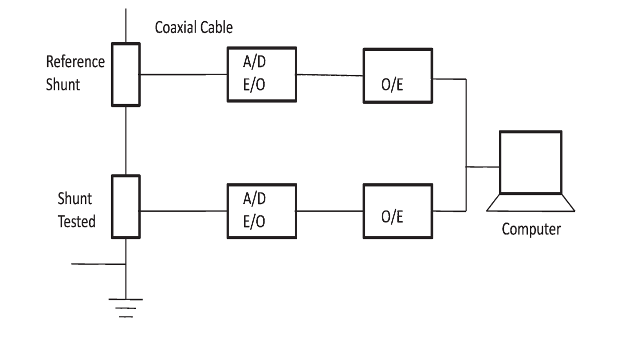

FIG. 8 ARRANGEMENT OF THE SHUNT TESTED

4.2.1 The scale factor tests

The scale factor tests were carried out with symmetrical currents of 0.1 s, with 10 peak values. The peak values of the symmetrical currents are from 10.1 kA to 75.1 kA depending on the rated values of the shunts tested. Table 4 shows the ratio between the values measured by the tested shunt (I_{test}) and those measured by the reference shunt (I_{ref}). Which were obtained by using 10 peak values of the symmetrical power frequency current. The averages of the scale factors at the 10 peaks obtained at the maximums and the minimums are given in Figure 6. The variation in the measured values of all 10 peaks and the average was less than 0.5 %, while the results show the variation in the scale factors of the shunts (their resistance value) was also less than 0.5 %.

TABLE 4		
SCALE FACTOR TEST AT 10KA RESULTS		
JSTC Shunt (in kA)	**CPRI Shunt (in kA)**	**% Deviation**
-10.11	-10.13	-0.19
-10.10	-10.12	-0.19
-10.08	-10.10	-0.19
-10.10	-10.12	-0.19
-10.08	-10.11	-0.29
10.11	10.18	-0.69
10.10	10.17	-0.69
10.09	10.16	-0.69
10.11	10.16	-0.49
10.11	10.16	-0.49

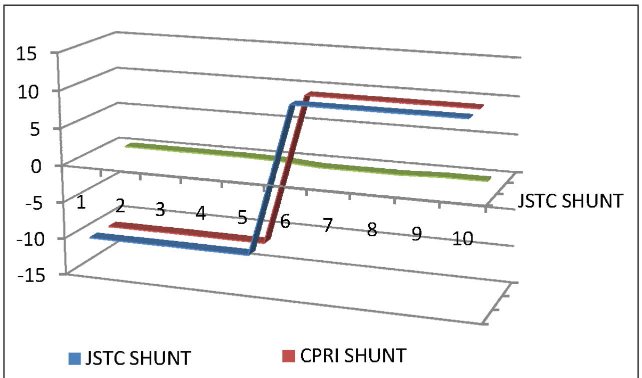

FIG. 9 AVERAGE SCALE FACTOR VARIATION DURING 0.1SEC SYMMETRICAL POWER FREQUENCY CURRENTS

4.2.2 Linearity tests with power frequency current

Linearity tests were carried out with asymmetrical currents at about 20,40,60,80 and 100% percentage of the maximum value, with a ratio of about 2.5 between the peak and the r.m.s. value. The tests were carried out at both polarities. While Table 5 shows the linearity test results obtained by the first peak value with asymmetrical power frequency currents. As shown in the Figure 7 for the entire current range, almost all of the differences are less than 0.5 %

4.2.3 Inerference tests with power frequency current

The shunt under test was disconnected and placed open-circuited at a distance of 0.5 m in parallel to the conductor in the test circuit and one terminal of the shunt tested was connected to the conductor. The current was measured by the reference shunt. Figure 8 shows the test arrangement for interference test. The interference is defined as the ratio between the currents measured in the disconnected shunt relative to the actual current measured by the reference shunt in the test circuit. Table 6 shows the interference test results. The interference is less than 0.47% of the actual current.

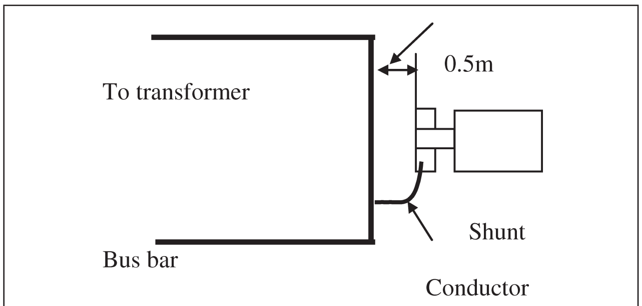

FIG. 10 TEST ARRANGEMENT FOR INTERFERENCE TEST

TABLE 6		
INTERFERENCE TESTS WITH POWER FREQUENCY CURRENT RESULT		
Test Current (in kA)	**CPRI Shunt (in kA)**	**% Measured**
100.8	0.1443	0.14
Maximum Deviation		0.14%
Standard Uncertainty		0.071%

4.2.4 Stability of the reference shunt resistance

The resistance of the reference shunt was measured at CRIEPI using the resistance bridge with a DC current of 10 A before and after the transportation of the reference shunt. Figure shows the resistance difference from the calibration at the DKD laboratory in Germany. The deference of resistance from the calibration at DKD d_f of the reference shunt is defined as follows:

$$d_f(\%) = \frac{R_m - R_c}{R_c} \text{ x } 100 \qquad ....(2)$$

Where

d_f = Resistance difference,

R_m = Resistance measured at CRIEPI before and after transportation

R_c = Resistance calibrated at DKD in Germany.

The difference was less than 0.05% (see Table 7) throughout the comparison test period, even though the reference shunt was transported from Japan to Germany, Korea, China, India and domestically. The results show that the reference shunt has good stability.

Uncertainty contribution due to the short-term stability as shown in Table 7.

TABLE 7

RESISTANCE VALUE RESULT

Before Test	After Test	Short term stability	Standard uncertainty
50.420uΩ	50.424uΩ	0.008%	0.004%

5.0 CONCLUSIONS

To establish traceability for high current measurements, comparison tests of high current shunts in high power laboratories have been carried out since 2005. In this project, two reference shunts were developed; one of which was used for Asia and the other for Europe and Africa. The main results of the comparison tests in Asia are as follows:

a) Reference shunts for high current measurement, which show the r.m.s value of symmetrical currents peaking at 140 kA, 0.1s and asymmetrical current peaking at 350 kA, were developed. The inter-comparison test results showed the values of differences which were determined to compare with the EDF shunt used as a reference shunt in the EC project were less than 0.1 % and revealed the performance to be good enough as reference.

b) Comparison test results of High power laboratories are summarized as follows.

c) The variation in the scale factor of the shunts with power frequency currents is less than 0.7 %.

d) Within the current range -250 to 250 kA, almost all of the scale factors varied by less than 0.7 %.

e) Interference with power frequency currents was less than 0.4 %.

f) The resistance variation of the reference shunt for Asia measured at CPRI before and after the transportation of the reference shunt, from the calibration at DKD of the reference shunt was less than 0.05 % throughout the comparison period. The results showed that the reference shunt has good stability.

g) It is recommended that the resistance of the shunt should be calibrated by a calibration laboratory and the comparison tests with high current using the reference shunt should be carried out at a certain intervals for example every five years for checking the high current performance.

The first round has been finished and the calibration and inter-comparison tests of two reference shunts for the second round will start shortly. This project revealed for the first time the performance of the high current shunts in high power laboratories participating the project in Asia are good enough for high power testing. The results are experience of the first round of comparison test will have a positive effect on a new IEC standard concerning high current measurements published in 2010[4].

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